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A comparison study of space borne Dual Polarization Difference Index (Sea Wind SCATSAT-1 Scatterometer) and NDVI (MODIS) on paddy crop growth

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Paddy rice occupied higher position among the staple food crops in the world. Paddy being a wetland crop; it requires more water than the other crops. India is one of the largest paddy producers in the world. Andhra Pradesh is the second largest paddy producer in India after West Bengal. In the latest era of technology, microwave remote sensing play major role in large scale monitoring of crop growth irrespective of environmental condition. In the present study dual polarized pencil beam SCATSAT-1 (Scatterometer Satellite 1) scatterometer and MODIS (Moderate Resolution Imaging Spectroradiometer) NDVI (Normalized Difference Vegetation Index) datasets are used to study paddy crop growth. Horizontal and vertical polarisation brightness temperatures were used to derive Dual Polarization Difference Index (DPDI) for paddy and forest classes. The DPDI was related with 16-day composite of NDVI data of MODIS sensor. To test the hypothesis, *z*-test was performed for testing significance between DPDI and NDVI. In the *z*-test the calculated value 11.455 is greater than table value 2.576, hence alternate hypothesis is accepted. Therefore, it is statistically proved that DPDI-NDVI relationship is influenced by soil moisture.

[**Keywords**: DPDI, MODIS-NDVI, Paddy, SCATSAT-1, Soil moisture]

Introduction

Paddy crop (rice) feeds around 3 billion people worldwide. It occupied 13 % of cropland in the study area with an annual production of 150 tonnes. The temporal evaluation of paddy crop and its growth improves the ecosystem balance; therefore, paddy crop has supreme importance in yield prediction and studying the earth climate[1,2]. It helps to study climate analysis and yield of the crops, because heat, energy and moisture between atmosphere and land surface influence the vegetation cover[3]. Remote sensing plays major role to analyse the vegetation in large scale. Electromagnetic radiation energy provides the information of vegetation without any physical contact. The optical red and NIR reflectance values are used to derive the Normalised Difference Vegetation Index (NDVI), it is extensively used to estimate biophysical parameters comprising LAI (Leaf Area Index), fractional vegetation cover and biomass[4]. The optical data of the region is affected by clouds, aerosol, water vapor and ozone. It creates difficulty to monitor kharif crops in monsoon period of India. The only solution for continuous monitoring is microwave remote sensing. The widely used microwave remote sensing systems for vegetation applications are synthetic aperture radar (SAR) and scatterometer platform. SAR has been extensively used for crop monitoring as well as for estimation of soil moisture, but its applications is limited by revisit period[5-7]. Passive microwave scatterometer and radiometers although limited by resolution have global applicability to monitor vegetation and land surface temperature. SCATSAT-1 has scatterometer sensor onboard with operating in Ku-band at 13.5 GHz frequency. It provides 3 types of data; they are sigma, gamma, and brightness temperature data. SCATSAT-1 provides brightness temperature in two polarisations; they are horizontal and vertical polarizations. SCATSAT-1 scatterometer sensor can get surface and atmosphere objects information in all weather conditions due to its penetration capability through clouds as the sensor operate at 13.5 GHz which is lower than P band.

Alexakis *et al*.[8] developed and demonstrated new microwave vegetation indices (MVIs) using AMSR-E observations. They found emission signals of a surface for two adjacent frequencies which are polarization independent with coefficients. Shi *et al*.[9]

identified that simultaneous observations at 10 GHz and 36 GHz in vertical and horizontal polarizations, particularly when united with thermal infrared measurements are beneficial in recognising different crops and identifying moisture conditions of the surfaces. Paloscia & Pampaloni[10] analysed brightness temperature (TB) of vegetation classes using microwave imager (SSMI) data throughout Kharif season. Horizontal and vertical polarisations are used to derive Microwave Polarization Difference Index (MPDI). They concluded that soil moisture in rice crop is influenced the NDVI-MPDI relationship. Singh & Dadhwal[11] executed classification of crop and soil using Ku-band and C-band SAR data. The authors recommended an automated retrieval of paddy growth stages coupled with FOS (Feature Optimization Strategy) and in association with SVM and SFS (Sequential Forward Selection). The authors also recommended some of the limitations derived from the study of Ku-band and C-band sigma-0. Li *et al.*[12] did study with RADARSAT-2 data to classify and map the rice crop. The authors achieved polarimetric response from paddy field by implementing compact pol retrieval algorithm. Further, Lopez-sanchez *et al.*[13] performed crop classification coupled with Landsat and SAR time series data. The authors did paddy classification along with the PMI (Paddy Map Index) based method. They concluded that the spatial distribution of rice was well represented with PMI. The authors created maps for large areas by coupling of Google earth and PMI-based approach. Park *et al.*[14] used NDVI and MPDI to monitor vegetation. They used Nimbus 7/SMMR at 37 GHz and NOAA/AVHRR data. Finally, the authors identified the relationship between the water content and chlorophyll absorption.

From the previous studies it is observed that they performed the study using quad pole data and they did not make study on duel pole data. SCATSAT-1 was launched in 2016 by ISRO and there is no study performed on duel polarized index, therefore this study aims to fill this research gap. The main objective of present study is to identify the influence of soil moisture on Dual Polarized Difference Index (DPDI)-NDVI relationship.

Materials and Methods

Study area

The current work is performed in Chittoor district of Andhra Pradesh, India. The study area lies in 13°22”18’ N, 79°10’10’ E coordinates. Andhra Pradesh is rich in agricultural activities due to abundant water supply with three major rivers namely Krishna, Godavari and Penna. The main source of food in Andhra Pradesh is from paddy. Andhra Pradesh state has long coastline with 972 km share with Bay of Bengal. The minimum rainfall of the state is 925 mm. The South-West and North-East monsoons are the major source for rain in the state. Traditional cultivation and harvesting methods are being practiced in the state.

The geographical area of Chittoor district is 15,152 km^2. The study was performed along the eastern part of the district. The high amount of agricultural land in eastern part of Chittoor district is used for practicing paddy cultivation because of the huge availability of ground water and rivers like Swarnamukhi river and Telugu Ganga canal. The paddy cultivation is a major agricultural practice in the study area. Therefore, the study site is elected as a test site to perform research. The research sample points have carefully chosen based on the SCATSAT-1 resolution i.e. 2 km. Figure 1 shows the geographical location of the study area.

Data used

SCATSAT-1 (ISRO) scatterometer and MODIS NDVI data are used to identify the influence of NDVI-DPDI on paddy crop. Both passes of vertical and horizontal polarized brightness temperature data with 2 km resolution are used. To convert the given brightness temperature data into ^{o}K (degree Kelvin) the following formula is used (Eq. 1). Table 1 shows the specifications of microwave Ku-band scatterometer and MODIS NDVI data. The brightness temperature from Ku-band SCATSAT-1, and NDVI from MODIS[15-17] are used in the study.

$$^{0}K = (DN * scale) + offset \qquad \dots (1)$$

Scale = 0.01, offset = 0 (as per SCATSAT-1 data product guide)

Figure 2 shows the detailed methodology performed in the present research work. SCATSAT-1 provides dual polarized brightness temperature data and MODIS provided NDVI data. The Dual Polarised Difference Index (DPDI) was calculated by using both brightness temperature and NDVI. In DPDI, vertical polarised (BV) and horizontally polarized (BH) brightness temperatures are used and in the NDVI optical bands i.e. RED and NIR were used. The DPDI calculation is performed by substitution of BV, BH, NDVI in equation 8.

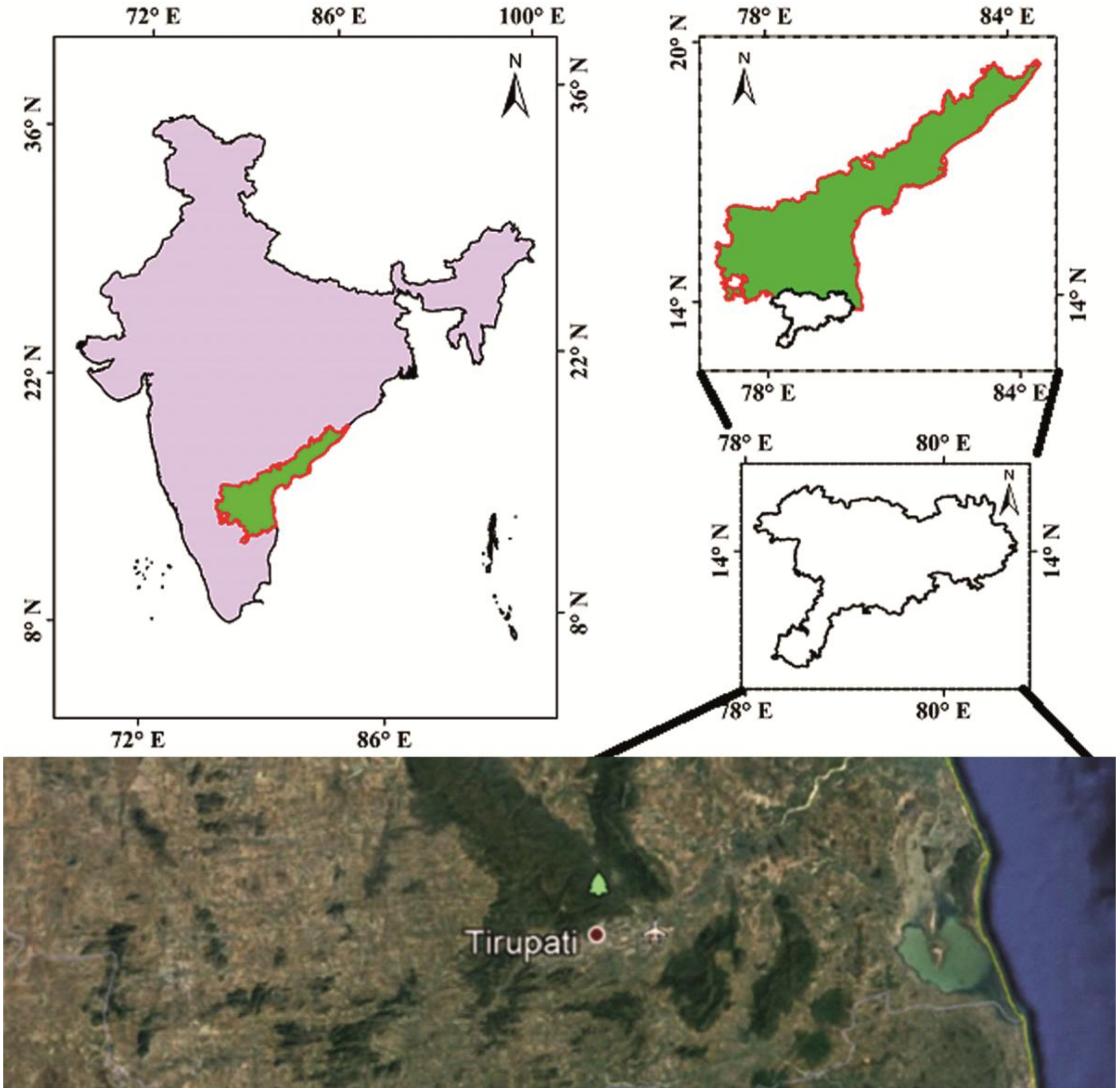

Fig 1 — Geographical location of the study area

Table 1 — Microwave data sensors specifications

S. No	Parameter	SCATSAT-1	NDVI
1	Frequency	13.515 G HZ	1.26 G HZ
2	Resolution	2km	250 m
3	Orbital period	99.19 min	16 days
4	Antenna	1m	17.7
5	Band	Ku	NIR, RED
6	Polarization	VV, HH	-

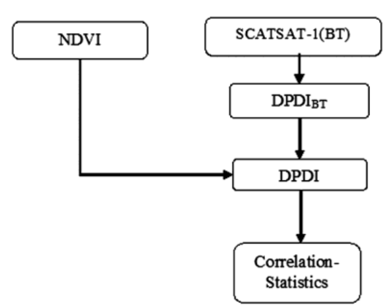

Fig 2 — Detailed methodology adopted to identify correlation statistics

Microwave radiometry

Microwave radiometer (MWR) is a radiometer used to measure the energy (1-1000GHz) emitted from the surface. The MWR are very sensitive receiver developed to estimate electromagnetic radiation (EMR). Passive microwave sensor measures the thermal emission from earth surface. Radiance temperature (Brightness temperature) is a measurement of the radiance. The spectral existence of a black body radiator is estimated by Rayleigh-Jeans formula as provided in equation 2.

$$B = 2 * k * T / (\lambda)^2 \quad \ldots (2)$$

where, T is temperature, k is Boltzmann constant and λ wavelength.

Power connected to a linearly polarized antenna for a black body is calculated as given in equation 3.

$$P = k * T * \Delta f \quad \ldots (3)$$

Since blackbody reflects more energy at a given temperature than any other body at the same temperature, the brightness temperature of a real material considered as the brightness of an equivalent black body at low-temperature T and it is provided in equation 4.

$$B_i(\theta,\phi) = \frac{2(k * \left[T(\theta,\phi)\right]}{\lambda^2} \quad \ldots (4)$$

where, θ, ϕ are incident angle and azimuth angle respectively, T_i is material brightness temperature, i refers to vertical and horizontal polarization.
Material emissivity is provided in equation 5.

$$\varepsilon_i(\theta,\phi) = \frac{B_i(\theta,\phi;T)}{B_b(T)} \quad \ldots (5)$$

$$= \frac{T_{Bi}(\theta,\phi)}{T}$$

$i = v \text{ or } h$

The agricultural region emissivity depends on angular geometry, polarization, frequency and surface characteristics *viz*., vegetation cover, surface roughness and soil moisture. Generally, the emissivity of horizontal polarization is lesser than vertical polarization. Wet soil has less emissivity compared to dry soil and increases with the surface roughness by increasing brightness temperature. DPDI and NDVI theoretically related to LAI and vegetation fraction. The change between transmissivity and reflectance of a plant in the NIR and visible region is due to chlorophyll absorption. The NDVI is derived from the equation 6.

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad \ldots (6)$$

where, NIR is infrared band and RED band in the visible region. The vegetation in the microwave region acts as an absorbing/scattering medium for radiation emitted from soil. The reduction of radiometric sensitivity to soil moisture is due to vegetation. The radiation emissivity increases with increase in vegetation as compared to barren field. Horizontal and vertical emissivity increase with increase in vegetation cover but the comparative change between the emissivity decreases. The microwave polarize difference index[18] is derived from the equation 7.

$$DPDI_{BT} = 100 * \left(\frac{T_{BV} - T_{BH}}{T_{BV} + T_{BH}}\right) \quad \ldots (7)$$

where, T_{BH} and T_{BV} are brightness temperatures of horizontal and vertical polarization. 100 is multiplied to the equation to make DPDI comparable to NDVI. Modelled response of vegetation in Microwave and optical region and is provided[18] in equation 8.

$$DPDI = DPDI_0 + \left[\frac{NDVI_M - NDVI}{NDVI_M - NDVI_0}\right]^{2\gamma} * \left(DPDI_M - DPDI_{BT}\right) \quad \ldots (8)$$

where, $NDVI_M$ and $DPDI_M$ are values of maximum vegetation and dual polarization difference index, respectively. $NDVI_0$ and $DPDI_0$ are values of low vegetation and dual polarization difference index, respectively. γ is unknown parameter and it is calculated using least square method for kharif season.

Testing of hypothesis

T-test and *z*-test are two statistical tests to test the hypothesis. Z statistical test is used for testing of hypothesis and it is used to determine whether two means are different when the variance is known. *Z*-test is a statistical test for which the test statistic under the null hypothesis is estimated by a Gaussian distribution. *T*-test is used for small samples (< 30), and the z-test is used for large samples (> 30)[19]. *T*-tests are of two types they are paired and unpaired *t*-tests. In the present study unpaired *z*-test is performed. *Z*-tests are of four types, they are single mean, difference of mean, single proportion and multiple proportion *z*-tests. In the present study difference of mean type of *z*-test is performed to test the hypothesis. The *z*-test is performed to identify the influence of DPDI and NDVI on soil moisture. The *z*-test is performed using the following equations 9.

$$Z = \frac{\bar{X}_1 - \bar{X}_2}{SE\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \quad \ldots (9)$$

where, SE is standard error, $\bar{X}_1$, $\bar{X}_2$ are mean, and n_1 and n_2 are sample size.

Results and Discussion

Dual polarization difference index (DPDI) and normalised difference vegetation index (NDVI) relationships are developed for paddy and forest. Figure 3 shows the variation of DPDI for paddy crop and forest. The DPDI derived from the brightness temperature product of SCATSAT-1. It is known that brightness temperature is sensitive to soil moisture and vegetation. The DPDI and NDVI values are observed with high variation due to change in soil moisture. The DPDI sensitivity at low NDVI varied for different vegetation as well as for regions. The DPDI values are high for paddy crop as compared to forest. The DPDI values showed an increase where vegetation is decreased. Table 2 shows the summary of statistics for DPDI and NDVI. Inverse relationship is observed between NDVI and DPDI for different vegetation. From Table 2, γ values are 0.59 and 0.71 for forest and paddy. It is observed that at lower NDVI, DPDI is high due to variations in soil moisture. The paddy crop shows higher NDVI value and lower γ value as compared to other vegetation. It may be due to soil moisture influence on the DPDI-NDVI relationship[20-22]. The correlation between the DPDI and NDVI is 0.81 for paddy and 0.61 for forest. Figure 4 shows temporal NDVI behaviour in the kharif season. The paddy response in Figure 4 shows highest vegetation between DOY 240 and 260. The NDVI shows paddy growth illustrated according to crop cycle. The present study demonstrates the potential of SCATSAT-1 data for agricultural applications. The *z*-test is performed between soil moisture and DPDI-NDVI to identify the influence of soil moisture in DPDI and NDVI relationship. Figure 5 shows the correlation of DPDI and NDVI. DPDI of paddy and forest disclose a sudden change before middle season because of their vegetation density and soil moisture variation. It is also observed that DPDI and NDVI response to paddy is similar at high vegetation and low DPDI, DPDI and NDVI response to paddy is quit opposite at low vegetation and high DPDI due soil moisture variations. The analysis is performed using ArcGIS, Origin 5.0 and excel platforms.

To test the hypothesis, *z*-test is performed and summery of *z*-test is shown in Table 3. In the *z*-test

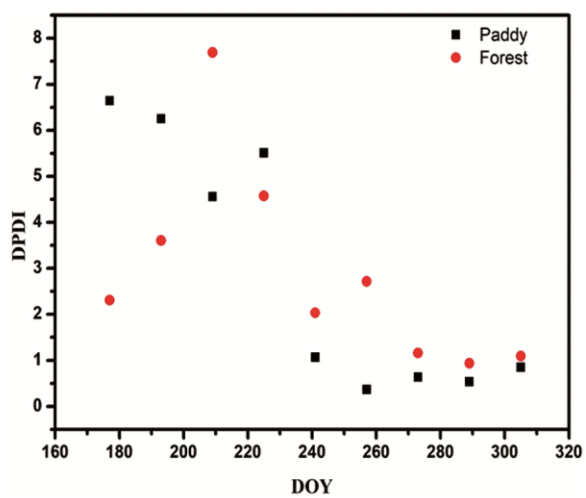

Fig 3 — Temporal DPDI for paddy and forest

Table 2 — Statistics of DPDI and NDVI

Class	$DPDI_M$	$DPDI_0$	$NDVI_M$	$NDVI_0$	n	γ	r
Paddy	14.00	-6.10	0.65	0.02	120	0.70	0.80
Forest	13.75	-10.70	0.87	0.30	120	0.55	0.64

r is a correlation, *n* is sample size, *γ* is an unknown parameter

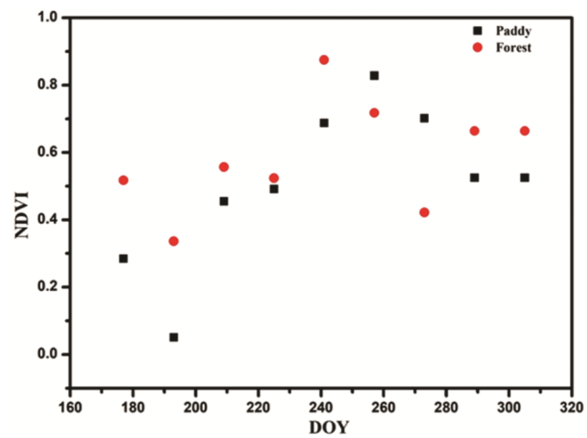

Fig 4 — NDVI time series analysis for paddy and forest

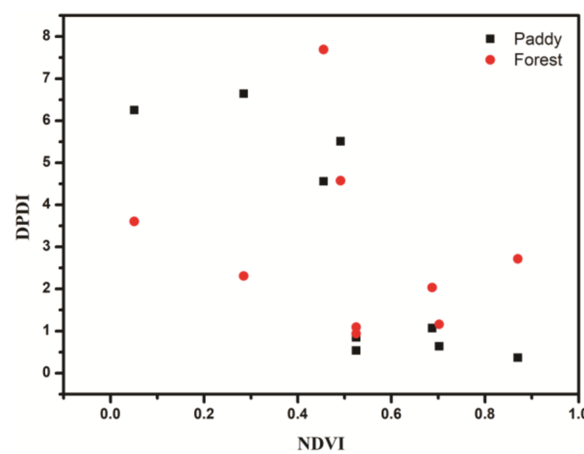

Fig 5 — NDVI and DPDI correlation for Paddy and Forest derived from SCATSAT-1 and MODIS

Table 3 — *Z*-test Statistics

N_1	N_2	$\bar{X}_1$	$\bar{X}_2$	σ_1	σ_2	SE	Z	Table value
60	9	0.836	1.823	0.157	1.812	0.675	11.455	2.576

the calculated value 11.455 which is greater than table value 2.576, therefore high significant influence on DPDI-NDVI by soil moisture, so null hypothesis h_0 is rejected and alternate hypothesis h_1 is accepted.

Conclusions

The SCATSAT-1 duel polarization brightness temperature data of 13.55 GHz are analysed for the Kharif season 2017 in Andhra Pradesh, India. Paddy crop and forest vegetation types are considered for comparative analysis. The microwave comprises of the electric field and magnetic field, of which the electric properties of wave are influenced by soil moisture. The amount of influence by soil moisture on electric properties of a wave depends on dielectric constant of soil. Moisture is a good conductor of electrons, so soil moisture definitely has a certain amount of influence on NDVI and DPDI. The *z*-test is performed to identify the soil moisture influence on DPDI-NDVI relation. In the *z*-test the tabulated value is 2.576 and the calculated value is 11.458. The *z*-test proved that tabulated value is lesser than calculated value, therefore it is statistically proved that there is a significant influence on NDVI-DPDI by soil moisture.

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Conflict of Interest

The authors are declaring that there no conflict of interest in the research.

Author Contributions

MP performed the research work and produced results using ArcMap 10 software platform under the guidance of KY.

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